Multimodality Imaging of Anatomy and Function in Coronary Artery Disease

Schuijf, J.D.

Chapter 3

Non-Invasive Coronary Imaging and Assessment of Left Ventricular Function using 16-slice Computed Tomography

Joanne D. Schuijf, Jeroen J. Bax, Liesbeth P. Salm , J. Wouter Jukema,
Hildo J. Lamb, Ernst E. van der Wall, Albert de Roos

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Abstract

Background

In recent years, multi-slice computed tomography (MSCT) has been demonstrated as a feasible imaging modality for non-invasive coronary angiography and left ventricular (LV) function analysis. The present study evaluates the overall performance of 16-slice MSCT in the detection of significant coronary artery disease (CAD), stent or bypass graft stenosis in combination with global LV function analysis.

Methods

In 45 patients, 16-slice MSCT was performed. From the MSCT images, the presence of significant coronary artery stenoses (≥50% luminal diameter reduction) in native coronary segments, bypass grafts and coronary stents were evaluated and compared with conventional coronary angiography. In addition, LV ejection fraction was calculated and compared to 2-dimensional echocardiography.

Results

MSCT was performed successfully in all patients. A close correlation between MSCT and 2-dimensional echocardiography was demonstrated for the assessment of LV ejection fraction ($y = 0.93x + 3.33$, $r=0.96$, $p<0.001$). A total of 298 (94%) of native coronary artery segments could be evaluated on the MSCT images, whereas 81 of 94 (85%) grafts and 41 of 52 (79%) coronary stents were evaluable. Including all segments, overall sensitivity, specificity, positive and negative predictive values were 85%, 89%, 71% and 95%, respectively.

Conclusion

16-slice MSCT is a feasible modality for the non-invasive evaluation and exclusion of CAD in patients presenting with chest pain.

Introduction

The introduction of 16-slice scanners has led to improved image quality in combination with shorter acquisition times and preliminary results show indeed a substantial improvement in terms of interpretability and accuracy in the evaluation of coronary arteries [1-3]. However, data are still scarce and have been obtained predominantly in carefully selected patient groups [1-3]. In these initial studies, simultaneous LV function analysis has not been performed, thus not taking full benefit of the acquired data. The present study evaluates the overall performance of 16-slice MSCT in the detection of significant coronary artery, stent or bypass graft stenosis in combination with global LV function analysis. Conventional coronary angiography and 2D-echocardiography served as the standards of reference.

Methods

Patients and study protocol

A total of 45 patients presenting with known or suspected CAD and scheduled for invasive coronary angiography due to chest pain complaints were included as part of ongoing protocols at our institution. Only patients in sinus rhythm and without contraindications to the administration of iodinated contrast media were included. All patients gave written informed consent to the study protocol, which was approved by the local ethics committee.

MSCT; Data acquisition

All MSCT examinations were performed with a 16-slice Toshiba Multi-slice Aquilion 16 system (Toshiba Medical Systems, Otawara, Japan). Collimation was 16 x 0.5 mm. If arterial grafts were present however, a collimation of 16 x 1.0 mm was used to reduce scan time. Rotation time was 400, 500 or 600 ms, depending on the heart rate, while the tube current and tube voltage were 250 mA and 120 kV, respectively. The total contrast dose for the scan ranged from 120 to 150 ml depending on the total scan time, with an injection rate of 4 ml/s through the antecubital vein (Xenetix 300®, Guerbet, Aulnay S. Bois, France). Automated detection of peak enhancement in the aortic root was used for timing of the scan. All images were acquired during an inspiratory breath hold with simultaneous registration of the patient's electrocardiogram. With the aid of a segmental reconstruction algorithm, data of two or three consecutive heartbeats were used to generate a single image.

For the assessment of LV ejection fraction, 2.0 mm slices were reconstructed in the short-axis orientation at 20 time points, starting at early systole (0% of the cardiac cycle) to the end of diastole (95% of the cardiac cycle) in steps of 5%. Images were transferred to a remote workstation with dedicated cardiac function analysis software (MR Analytical Software System [MASS], Medis, Leiden, the Netherlands).

To evaluate the presence of coronary artery stenoses, separate reconstructions in diastole (typically 75% or 80% of the cardiac cycle) were generated with a reconstructed section thickness of either 0.4 mm or 0.8 mm. If motion artifacts were present, additional reconstructions were made at 40, 45, and 50% of the R-R range. Axial data sets were transferred to a remote workstation (Vitrea2, Vital Images, Plymouth, Minn. USA) for post-processing and subsequent evaluation.

MSCT; Data analysis

Endocardial borders were outlined manually by an independent observer on the short-axis cine images. Papillary muscles were regarded as being part of the ventricular cavity. After calculation of LV end-systolic and LV end-diastolic volumes, the related LV ejection fraction was derived by subtracting the end-systolic volume from the volume at end-diastole and dividing the result by the end-diastolic volume.
MSCT angiograms were evaluated by 2 experienced observers, who were blinded to the results of coronary angiography. The following protocol was applied in the evaluation of the MSCT coronary angiograms: Of each patient, the 3-dimensional volume rendered reconstruction was inspected first to obtain general information of the status and course of the coronary arteries, and if present, coronary bypass grafts and stents. In patients without coronary bypass grafts, native coronary arteries were divided in segments according to the American Heart Association-American College of Cardiology guidelines and classified as evaluable or not by visual estimation. Subsequently, the interpretable segments were evaluated for the presence of significant narrowing (≥50% reduction of lumen diameter) using both the original axial slices and curved multiplanar reconstructions. In stented segments, the presence of restenosis was defined reduced run-off of contrast distally, whereas stent occlusion was defined as the absence of contrast within the stent in combination with the absence of run-off of contrast distally.
In patients with previous coronary bypass grafting, grafts and the distal course of the recipient vessels were evaluated first. Sequential grafts were considered as separate graft segments. Although patency was assessed in all grafts, the presence of luminal narrowing of 50% or more was determined only in grafts with sufficient image quality. If a graft demonstrated significant narrowing or total occlusion, native segments prior to the graft anastomosis were also evaluated. Remaining native vessels, e.g. vessels not supplied by coronary bypass grafts, were evaluated afterwards.

2D-echocardiography

For the comparison of LV ejection fraction, 2D-echocardiography was performed prior or after the MSCT examination within 3 days. Patients were imaged in the left lateral decubitus position using a commercially available system (Vingmed System FiVe/Vivid-7, GE-Vingmed, Milwaukee, WI, USA). Images were acquired using a 3.5 MHz transducer at a depth of 16 cm in the parasternal and apical 2-, 4- and 5-chamber views. LV ejection fractions were calculated by an independent observer without knowledge of the angiographic or MSCT data from the 2- and 4 chamber images using the biplane Simpson's rule [4-6].

Conventional coronary angiography

Conventional coronary angiography was performed according to standard techniques. The femoral approach with the Seldinger technique was applied to obtain vascular access. Average interval between conventional coronary angiography and MSCT was 18 ± 26 days. Angiograms were visually evaluated by consensus reading of two experienced observers without knowledge of the MSCT data.

Statistical analysis

Sensitivity, specificity, positive and negative predictive values for the detection of ≥50% luminal narrowing in respectively native coronary artery segments, bypass graft segments and stented segments were calculated. Coronary segments supplied by coronary bypass grafts were included in the native vessel analysis. For linear regression analysis of LV ejection fractions, the Pearson correlation coefficient r was computed. Bland-Altman analysis was performed for each pair of values of LV ejection fraction to calculate limits of agreement and systematic error between the two modalities [7]. A p-value <0.05 was considered to indicate statistical significance.

Results

MSCT was performed successfully in all 45 patients. Main clinical characteristics of the study population are listed in Table 1.

Table 1. Characteristics of the study population (n= 45).

	n (%)
Male/Female	42/3
Age (years)	63 ± 10
Heart rate during data acquisition	65 ± 10
Beta blocker medication	35 (78%)
Previous myocardial infarction	29 (64%)
Previous percutaneous coronary intervention	30 (67%)
Previous coronary bypass grafting	22 (49%)
Number of coronary vessels narrowed	
1	4 (9%)
2	10 (22%)
3	30 (67%)
Angina Pectoris	
Canadian Cardiovascular Society class 1/2	10 (22%)
Canadian Cardiovascular Society class 3/4	35 (78%)
Heart Failure	
New York Heart Association class 1/2	34 (75%)
New York Heart Association class 3/4	11 (24%)

LV ejection fraction

Average LV ejection fraction as determined by MSCT was 47 ± 13% (range 15% to 72%) and 47 ± 14% (range 16% to 75%) with 2D-echocardiography. Linear regression analysis (Figure 1A) demonstrated an excellent correlation (r=0.96, p<0.001) between both modalities. A mean difference of -0.02 ± 3.9% was demonstrated by Bland-Altman analysis (Figure 1B), not statistically different from zero.

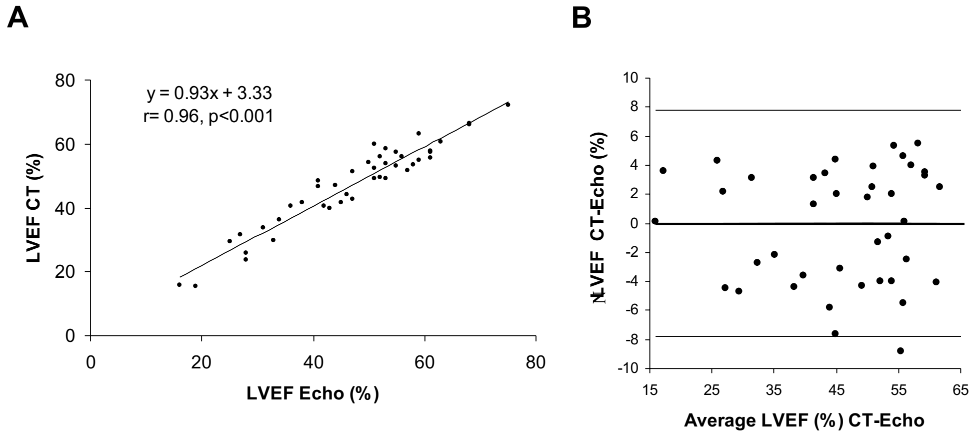

Figure 1. Comparison of MSCT and echocardiography in the assessment of LV function. Panel A represents a linear regression plot showing the correlation between the LV ejection fraction as determined by 2D-echocardiography and MSCT. In panel B, a Bland-Altman plot of LV ejection fraction is shown. The difference between each pair is plotted against the average value of the same pair (solid line= mean value of differences and dotted lines = mean value of differences ± 2SDs).
Abbreviation: LVEF: left ventricular ejection fraction.

Coronary angiography

Conventional coronary angiography, which was performed in 317 native segments, revealed narrowing of ≥50% of luminal diameter in 64 segments. A total of 298 (94%) of these segments could be evaluated on the MSCT images. Causes of uninterpretability were small size of the vessel (n=9), ectopic heartbeats (n=1), motion artifacts (n=4), vascular clips (n=1) and insufficient contrast (n=4). Significant stenoses were correctly identified in 59 segments, while the presence of significant stenosis was correctly ruled out in 231 of 253 segments, resulting in a sensitivity and specificity of 93% and 91%. Considering only the interpretable segments, sensitivity and specificity were 98% and 97%, respectively.
A total of 62 grafts (arterial grafts: 13, venous grafts: 49) of which 31 sequential grafts, were present, resulting in 94 graft segments. Total occlusion was correctly identified in 23 of 24 occluded grafts, whereas patency was correctly determined in all 70 patent grafts. Thirteen graft segments (all arterial grafts) were of insufficient quality to assess the presence of ≥50% stenosis. In the remaining 81 grafts, the presence of significant stenosis was correctly identified in all 27 grafts with 50% or more

narrowing. In 2 of 54 graft segments without significant stenosis however, the presence of stenosis was incorrectly observed on the MSCT images, resulting in a specificity of 96%.
Of the 52 stented segments that were present in the study population, a total of 41 (79%) was judged interpretable by MSCT. In the interpretable stents, 7 of 8 stented segments with significant in-stent restenosis and all patent stented segments (n=33, 100%) were correctly identified on the MSCT images. However, when uninterpretable stents were included in the analysis, sensitivity and specificity were 54% and 85%, respectively.
Details of all analyses including positive and negative predictive values are summarized in Table 2. Examples of MSCT images and corresponding conventional angiograms are depicted in Figure 2.

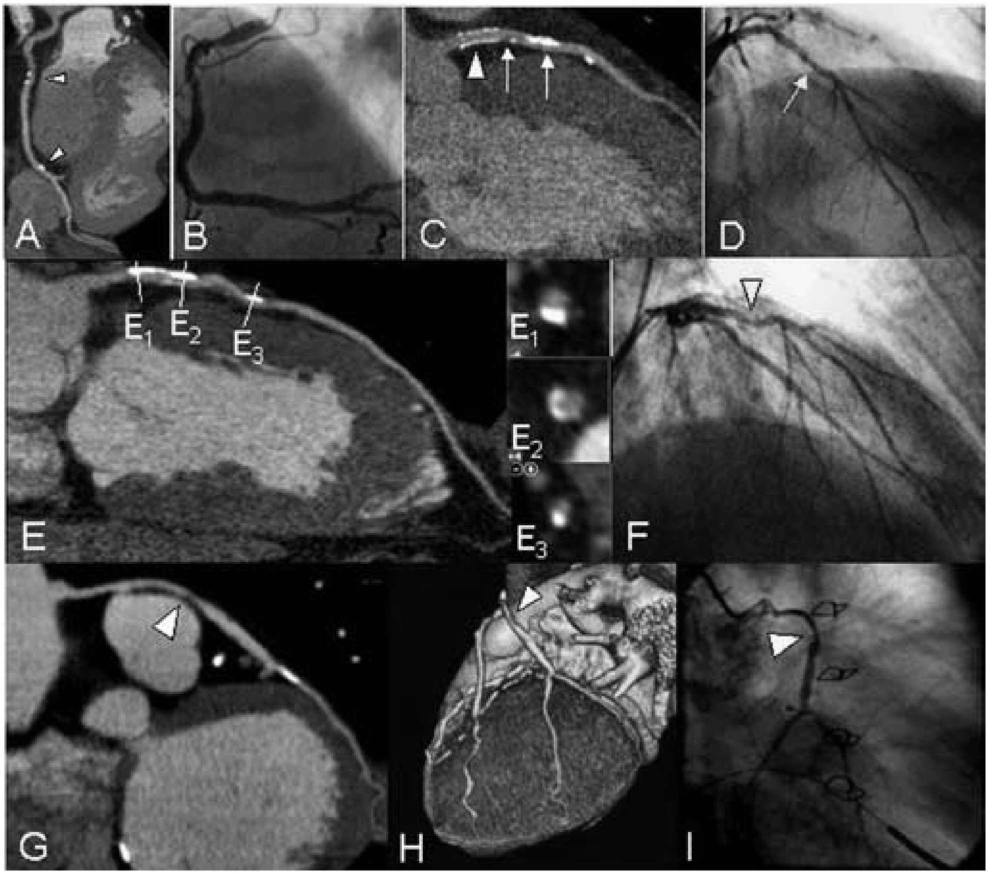

Figure 2. Non-invasive coronary angiography with MSCT

A: A curved multiplanar reconstruction of a right coronary artery with small calcifications (arrowheads) but no significant stenosis is shown. C: An example of a coronary stent (arrowhead) with no significant in-stent restenosis, placed in the proximal left anterior descending coronary artery. However, distal to the stent, both soft and calcified plaque can be observed (arrows). E: An example of an intermediate stenosis in the left anterior descending coronary artery is shown in panel E, while panels E_{1-3} represent cross-sectional images. G,H: An example of a venous bypass graft supplying an obtuse marginal branch is provided. On both MSCT images, a curved multiplanar reconstruction (panel G) and a 3D volume rendered reconstruction (panel H), narrowing of more than 50% lumen diameter is demonstrated. B,D,F,I: Corresponding coronary angiograms confrimed findings.

Table 2. Diagnostic accuracy of MSCT.

	Native segments (≥50% stenosis)	**Graft segments (occlusion)**	**Graft segments (≥50% stenosis)**	**Stented segments (≥50% in-stent stenosis)**	**All segments (≥50% stenosis)**
Evaluation possible	298/317 (94%)	94/94 (99%)	81/94 (85%)	41/52 (79%)	420/463 (91%)
Sensitivity	59/60 (98%)	23/24 (96%)	27/27 (100%)	7/8 (88%)	93/95 (98%)
Specificity	231/238 (97%)	70/70 (100%)	52/54 (96%)	33/33 (100%)	316/325 (97%)
Positive predictive value	59/66 (89%)	22/22 (100%)	27/29 (93%)	7/7 (100%)	93/102 (91%)
Negative predictive value	231/232 (100%)	70/71 (99%)	52/52 (100%)	33/34 (97%)	316/318 (99%)
Diagnostic Accuracy	290/298 (97%)	93/94 (99%)	79/81 (98%)	40/41 (98%)	409/420 (97%)
Including uninterpretable segments					
Sensitivity	59/64 (93%)	23/24 (96%)	27/32 (84%)	7/13 (54%)	93/109 (85%)
Specificity	231/253 (91%)	70/70 (100%)	52/62 (84%)	33/39 (85%)	316/354 (89%)
Positive predictive value	59/81 (73%)	22/22 (100%)	27/36 (75%)	7/13 (54%)	93/131 (71%)
Negative predictive value	231/236 (98%)	70/71 (99%)	52/57 (91%)	33/39 (85%)	316/332 (95%)
Diagnostic Accuracy	290/317 (91%)	93/94 (99%)	79/94 (84%)	40/52 (77%)	409/463 (88%)

Discussion

The results of the present study demonstrate that non-invasive assessment of the presence of CAD in patients presenting with chest pain is feasible with 16-slice MSCT. In 317 native coronary artery segments, a sensitivity and specificity of 93% and 91%, respectively, were demonstrated without exclusion of the 6% segments that were uninterpretable. These findings are in line with results of previous 16-slice MSCT studies [1-3;8]. Although in the individual studies observed sensitivities and specificities ranged from 89% to 95% and 86% to 98%, negative predictive values were consistently above 97%, similar to our results (98%). Thus, the current findings emphasize the potential of MSCT to serve as a first-line diagnostic modality to rule out the presence of CAD. This is an important finding since approximately 20% of invasive catheterizations are performed for purely diagnostic purposes and are not followed by any interventions. Therefore, MSCT may be particularly valuable to avoid the discomfort, risks and costs of invasive angiography in a considerable number of patients.
In all coronary bypass grafts, patency could be assessed with a high accuracy (99%). More subtle detection of graft stenosis, however, could be performed in only 85% of grafts, resulting in a sensitivity and specificity of 84%. Considering only interpretable bypass grafts, sensitivity and specificity were 100% and 96%, respectively.
Slightly lower results were observed in the evaluation of stented segments. Only 41 of 52 available stented segments could be evaluated for the presence of significant in-stent stenosis. In the interpretable stented segments, resulting sensitivity and specificity were 88% and 100%, respectively.

Thus, although patients with suspected in-stent stenosis may still benefit more from direct referral to invasive coronary angiography, MSCT may be particularly useful to evaluate patients with known or suspected CAD or with recurrent chest pain after coronary artery bypass grafting. In addition, information on LV function can be derived.

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